

Hyperloop Power Supply and Generation

Individual Report

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1.0 INTRODUCTION

With every concept, comes a barrage of obstacles dedicated to leaving the idea on the drawing board. However, when people dedicate themselves to overcoming this assault, the concept becomes reality. The concept in this case is the Hyperloop Project; the idea of an extremely high speed, energy efficient, land based transportation system which moves by magnetic levitation/propulsion through a vacuum. Drawbacks and difficulties can be thought of instantly: How will the magnets be designed to move it? Will they be strong enough? Will it be safe under unexpected abnormalities? How will it be powered? Our group has been tasked with conquering one of these major obstacles; to power the unit safely, efficiently, and with minimum weight as possible.

2.0 DESIGN WORK

2.1 Block Diagram and Personal Task

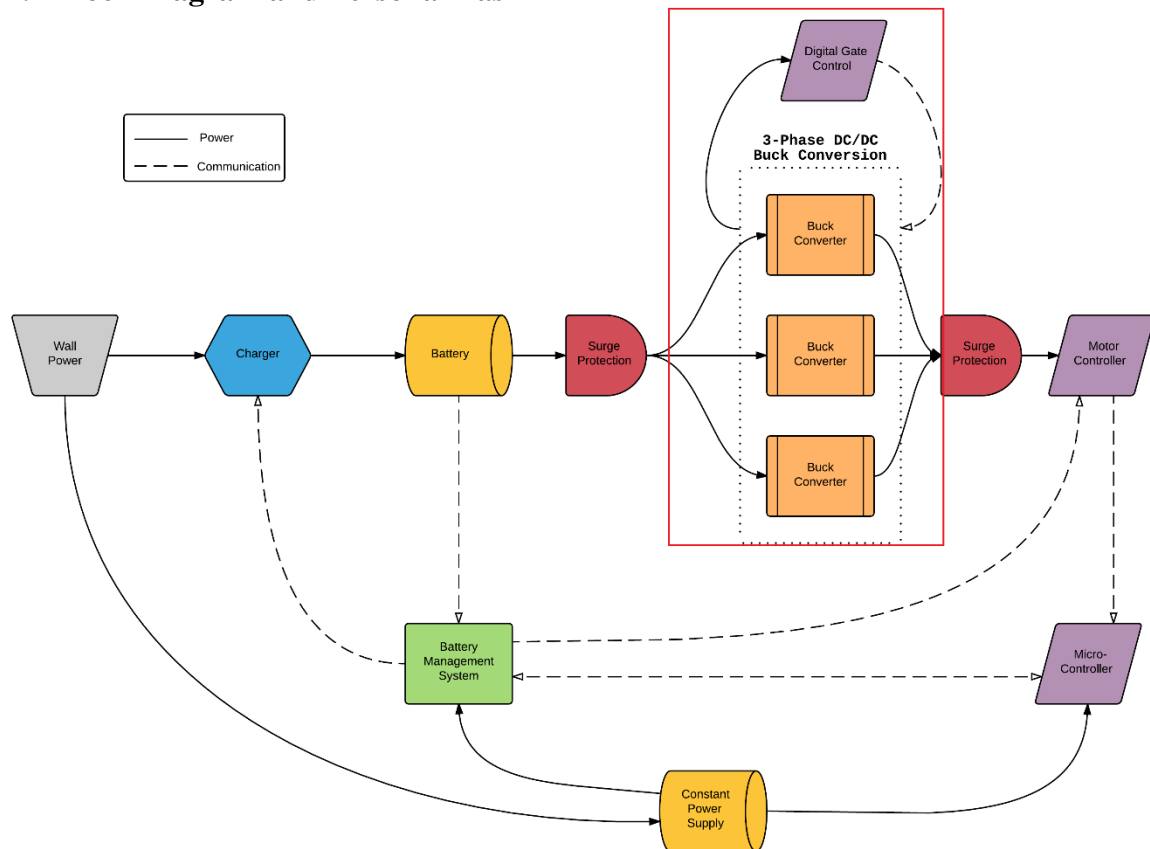


Figure 1: Overall Block Schematic with personal task in the red box

The layout of our project has not changed at all. The converter however, has been changed, since we realized later that it would be feasible to carry a much larger input source. We then decided to make a buck converter, which would give us a significantly smaller current strain on our components. The new parameters will be shown in the calculations and explanations below. My personal task is to create all the design and stimulation aspects of a 3-Phase Buck converter that can fill out our voltage input/output needs.

2.2 Concept

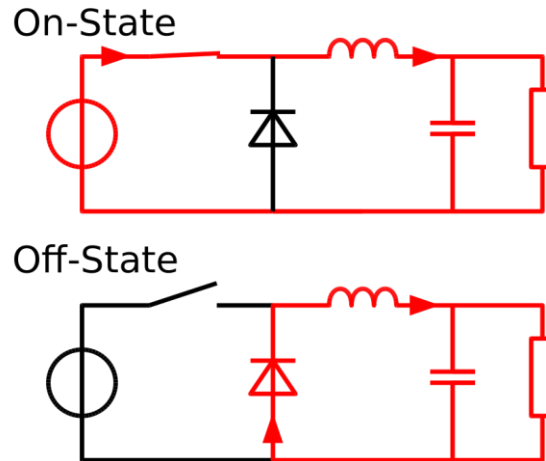


Figure 2: ON(above) and OFF(below) stages with the red representing current flow [1]

The purpose of a DC-DC Buck Converter (also known as a Step-Down Converter) is to take a voltage source input and lower its output voltage by a specific factor, while still delivering current/power as efficiently as possible. The circuit of the converter is shown in *Figure 3*. Its function is controlled by MOSFET that switches on/off as a very high frequency, in order to create a desired average output voltage/power. The MOSFET's period can be split into two states, for when the switch is on/off, as shown above in *Figure 4*. When the MOSFET is on, the voltage source can directly charge the inductor, output capacitor, and power the load, while the diode is off due to the current flow. When the MOSFET is turned off, the load is no longer attached to the source and is thus powered by the discharging inductor and output capacitor, also turning on the diode for passage. The frequent discharging/charging creates a triangular wave voltage output which averages to the desired value

2.3 Calculations and Circuit Design

Various equations based off the converter circuit's behavior are used to calculate the values of its components so that they will meet our specifications. Although we were planning to make a 3-phase Buck Converter, the calculations were made for a single phase converter since they could easily be adjusted (shown later) to match the 3-Phase converter's. The specs we made for a single-phase Buck Converter were:

(2.3.1)

$$f_s = 100\text{kHz} \Rightarrow T = 10\mu\text{s}$$

$$\langle P_{out} \rangle = \langle P_{in} \rangle = 1.2\text{kW}$$

$$V_{in} \approx 162\text{ V}$$

$$V_{out} = 72 \pm 5\% \text{ V}$$

Where f_s is the switching frequency, T is the period, V_{in} and V_{out} are the respective supply and ideal load voltages, and $P_{in/out}$ is the power supplied/consumed. We had chosen 100kHz as a frequency since it was a proper middle ground and allowed us more flexibility in inductor material. Since under ideal conditions, by following the Law of Conservation of Energy, the input and output power are identical, thus allowing us to use the following equation to get the input/output currents I_{in} and I_{out} :

(2.3.2)

$$1200\text{ W} = V_{in} * I_{in} = V_{out} * I_{out} \Rightarrow I_{in} = 7.41\text{ A}, I_{out} = 16.67\text{ A}$$

The next step is to obtain the Duty Cycle; the time the MOSFET is on during each period. Since we know an inductor's average voltage should be zero in steady state, we can use this as a reference point to create two equations that will extract our Duty Cycle:

(2.3.3)

$$\langle V_L \rangle = 0\text{V}$$

Switch ON

$$V_L = V_{out} - V_{in}$$

Switch OFF

$$V_L = V_{out}$$

The ON time normalized can be considered a length of D (our Duty cycle), while the OFF time is difference of time left until the full period.

(2.3.4)

$$\langle V_L \rangle = D(V_{out} - V_{in}) + (1 - D)(V_{out}) = 0\text{V}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = D = \frac{72}{162} = .44 \text{ or } 44\%$$

The next step is to obtain our inductor value, which is needed to make the peak-to-peak current of the inductor equal to twice the value of our load. We can solve this by using Equation (2.3.3) in conjunction with the formula used to obtain the voltage of an inductor in the time domain.

(2.3.5)

$$\Delta I_{Lpk - pk} = 2 * I_{in} = 33.33 A$$

$$V_L = L \frac{di}{dt} \Rightarrow L = V_L * \frac{dt}{di} = -90 * \frac{DT}{\Delta I_{Lpk - pk}} = 12 \mu H$$

Our final component to calculate the minimum output capacitance to keep our output voltage ripple within a 5% range. This is done by looking at the average current that would go through the capacitor during either the ON or OFF time (I chose to use ON for the equation), and use Ampere's Law to obtain the capacitance, since we know our change in V_{out} and in time t :

(2.3.6)

$$I_C = C_{out} \frac{dV_{Cout}}{dt} \Rightarrow C_{out} \geq \frac{I_C * DT}{(72) * (.05)} = 20.56 \mu F$$

Now that we have all of our components, we can build the circuit on a simulator and test to make sure it works. Since, the real world is not ideal, we will be expecting a loss of energy throughout the circuit, which will determine our efficiency below:

(2.3.7)

$$\eta = \frac{P_{out}}{P_{in}} \rightarrow \frac{I_{in}}{I_{out}} \text{ or } \frac{V_{out}}{V_{in}}$$

This factor is quite important for our specific case since our load is self-adjusting in resistance. The Motor Controller will ensure that it receives 3.6kW of power total, therefore taking in more current to make up for any loss in voltage, which in turn will force our batteries to supply more power in order to provide this current. This is opposed to the usual system where the output has a smaller power than the input by having a constant load, which would result in a smaller V_{out} creating a smaller I_{out} .

The simulated circuit on *LTSpice* is shown below, with some of the components tweaked to make up for internal resistances.

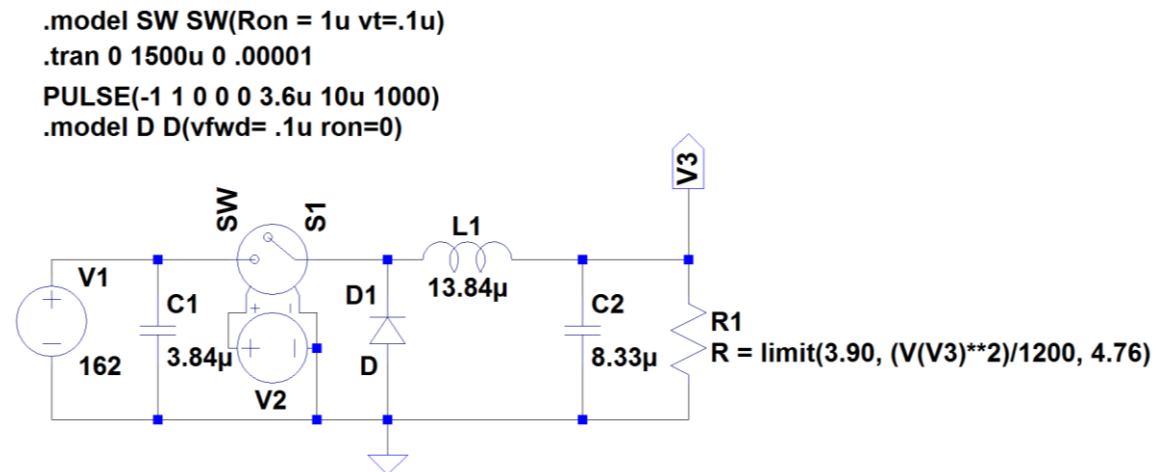


Figure 3: Single Phase Buck Converter used for initial simulation

In order to create a three phase system, we simply need to create three Step-Down systems and delay their switching responses by a third of the of period from each other. For the sake of efficiency and surge prevention, our diode has been replaced by a MOSET that is ON inversely to our original one. Our inductor is divided by a factor of 3 and put into each phase, since our output current is now 50 Amps. The capacitors were only split for financial purposes, since a 30 μ F capacitor would cost significantly more than three 10 μ F ones.

This system significantly reduces the stress on the MOSFETs and the inductors, while also creating a smoother output waveform, thus increasing efficiency in the process, while adding a negligible amount of weight to the device.

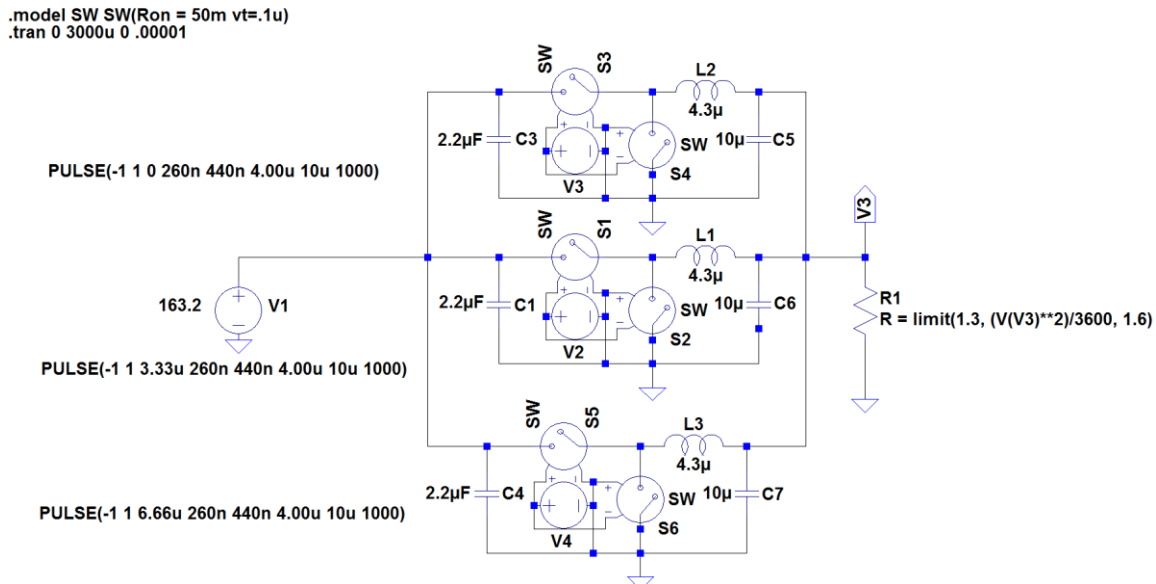


Figure 4: Three Phase Buck Converter used for final simulations

2.4 Parts

All parts that have been selected fit and go above the simulated voltage and current ratings, and can handle surges without breaking.

Component	Manufacturer/Model	Cost Per Unit	Quantity Needed
Input Capacitor	United Chemi-Con KHC201E225M76N0T00	\$4.85	3
MOSFET	Fairchild Semiconductors FDP39N20	\$1.20	6
Inductor	Coilcraft AGP2923- 472KL	\$5.60	3
Output Capacitor	Cornell-Dashiel 935C4W10K-F	\$18.06	3
Power Connector Housing	Anderson Power 992G1- BK	\$1.32	2

Power Connector Contact	Anderson Power pc5930s	\$5.51	4
Gate Driver	Fairchild Semiconductors FAN7382	\$.70	3
8-Pin Sockets	110-13-308-41-001000	\$.77	3
Digital Control	Texas Instruments F28027	\$17.30	1
Signal Connector	Anderson Power A108330-ND	\$1.24	1

Table 1:

2.5 PCB Design

Since our circuit is a high power one, our printed circuit board must be a multilayered one in order to prevent the small-signal and power traces from interfering. Our trace thickness and width must also be modified in order to accommodate for our large currents. Unfortunately, I am still working on the PCB board layout, since these conditions introduce new variables and factors when laying out the board. This is currently the highest priority of our project and will be finished as soon as possible.

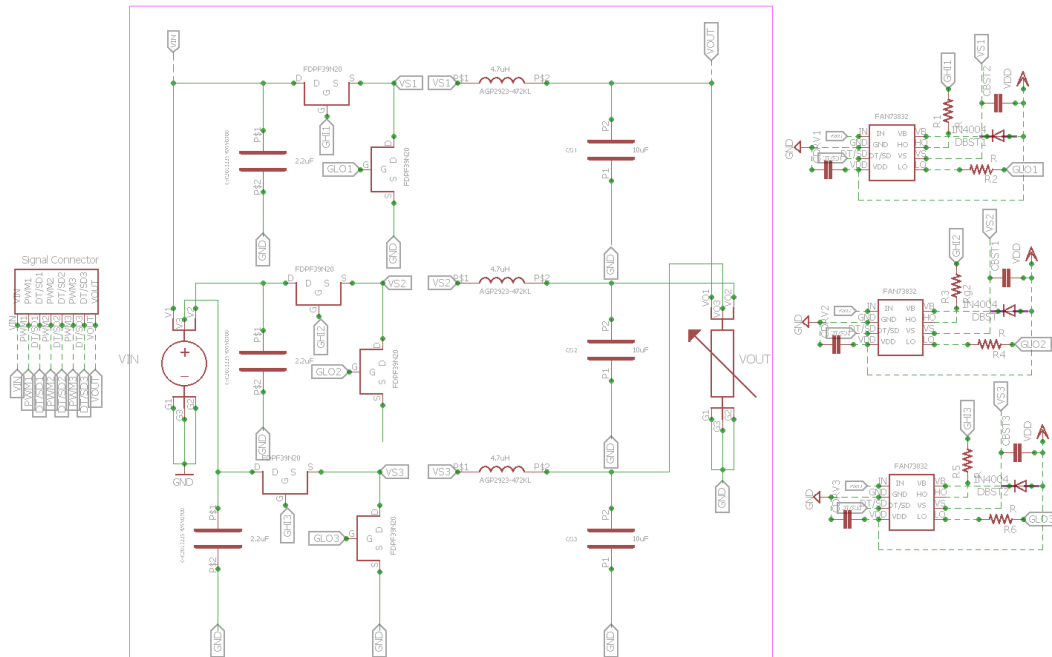


Figure 5: EagleCAD schematic of the full circuit with chosen devices

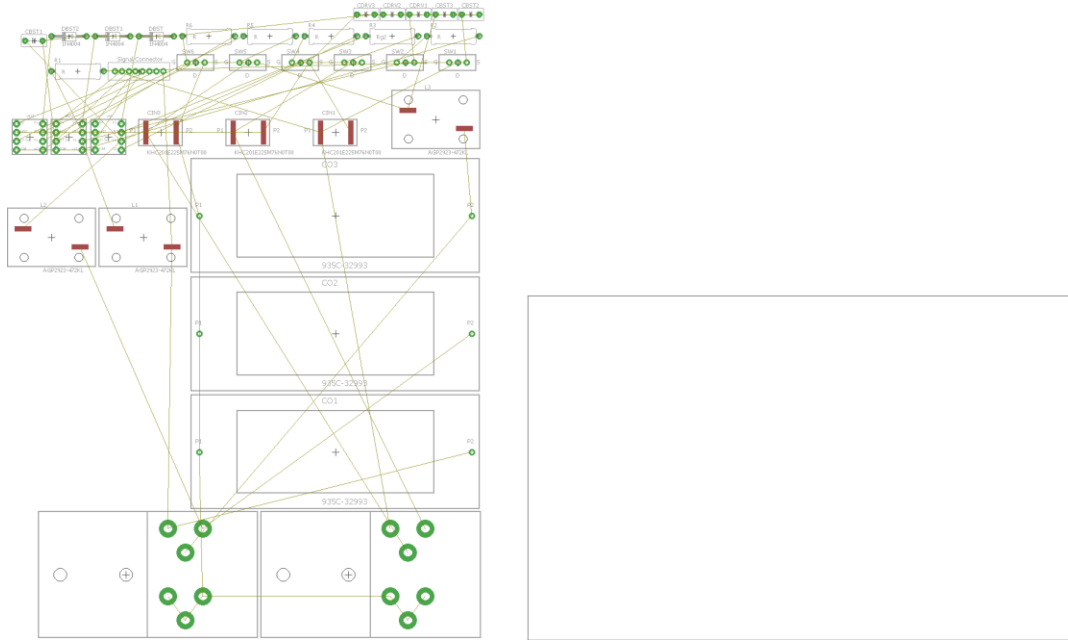


Figure 6: The undeveloped layout of our multi-layer PCB(currently being worked on)

3.0 VERIFICATION

Since we cannot test our circuit out yet, we have not been able to make verifications yet. Under simulations which included the delays, internal resistances, etc. from the component data sheets, these are the predicted conditions for the components, and were also when shopping for parts.

Component	Conditions
Input Capacitor	$I_{rms}=0A$, $V_{rms}=163.2V$
MOSFET(High Side)	$I_{rms}=22.686A$, $V_{rms}=122.76V$
MOSFET(Low Side)	$I_{rms}=25.656A$, $V_{rms}=106.35V$
Inductor	$I_{rms}=34.712A$, $V_{rms}=80.3V$
Output Capacitor	$I_{rms}=9.36A$, $V_{rms}=70.4V$

Table 2: The conditions the converter parts must endure assuming minimal surges

4.0 CONCLUSION

As mentioned before, our highest priority is to send our PCB design to a fabrication lab in order to test it. After the PCB is sent in, our group will be collectively finishing the remaining task

4.1 Timeline

<i>Dates</i>	<i>Plans</i>
1st April	Finish PCB Layout and go over with TA
2nd-7th April	Familiarize and practice with needed equipment to assemble the Hyperloop Project
8-16th April	Hopefully receive PCB and finish assembling our circuit to present as a demo
18th-25th April	Assemble Hyperloop Project and prepare it for demonstration
26th April-5th May	Prepare presentation and final report

Table 3: Timeline for the remainder of our project

4.2 Ethics

1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;
3. to be honest and realistic in stating claims or estimates based on available data;
5. to improve the understanding of technology; its appropriate application, and potential consequences;
7. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
9. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others; [3]

These ethics pertain to us the most since our project poses huge risk for those unfamiliar with safe electrical practices. It is our duty to present this information and *always* point out when we are unsure of something that may pose a risk to others.

5.0 REFERENCES

- [1] Wikipedia Article on Buck Converters. Available at:
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Accessed March 2015
- [2] Krein, Philip T. *Elements of Power Electronics*. 2nd ed. New York: Oxford UP, 2015.
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